

Rocket Motor Microphone Investigation

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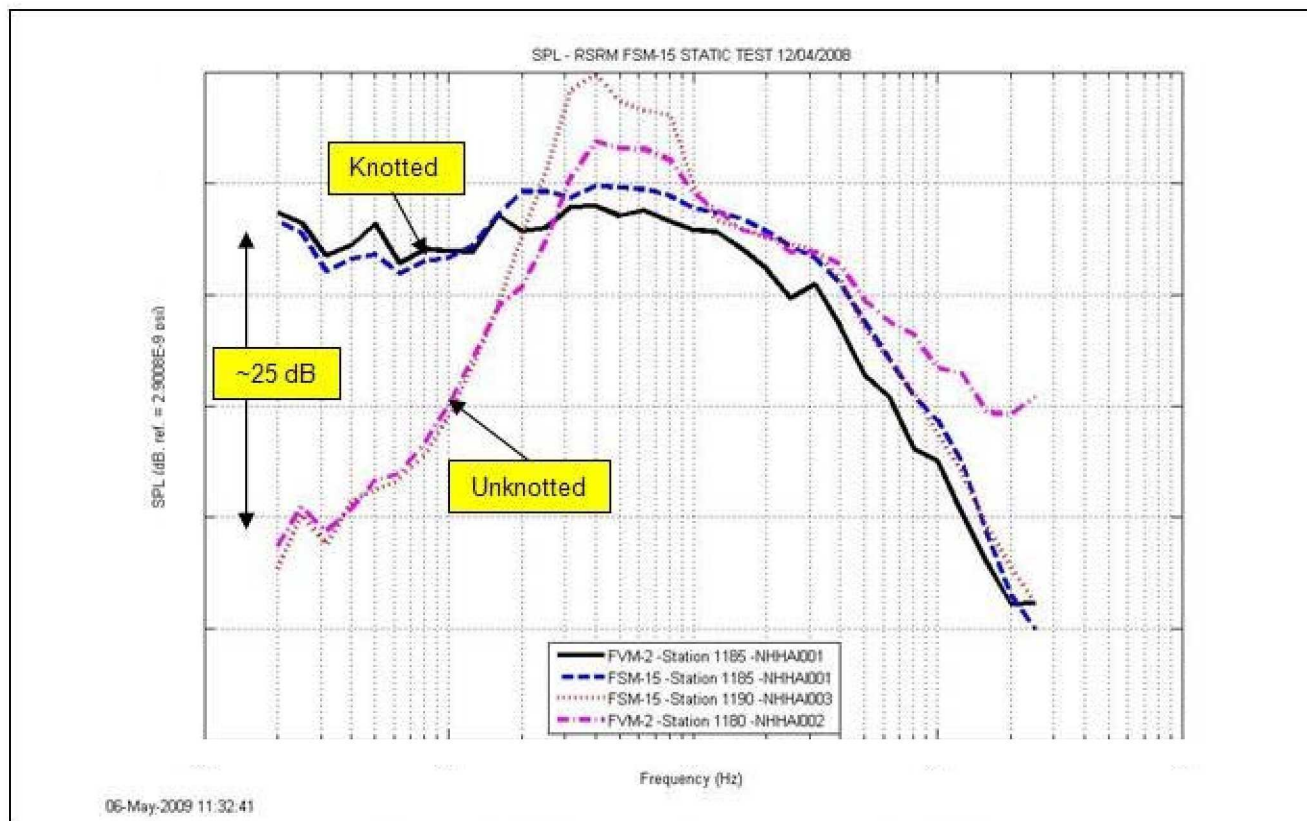


At ATK's facility in Utah, large full-scale solid rocket motors are tested. The largest is a five-segment version of the reusable solid rocket motor, which is for use on the Ares I launch vehicle.

As a continuous improvement project, ATK and BYU investigated the use of microphones on these static tests, the vibration and temperature to which the instruments are subjected, and in particular the use of vent tubes and the effects these vents have at low frequencies.



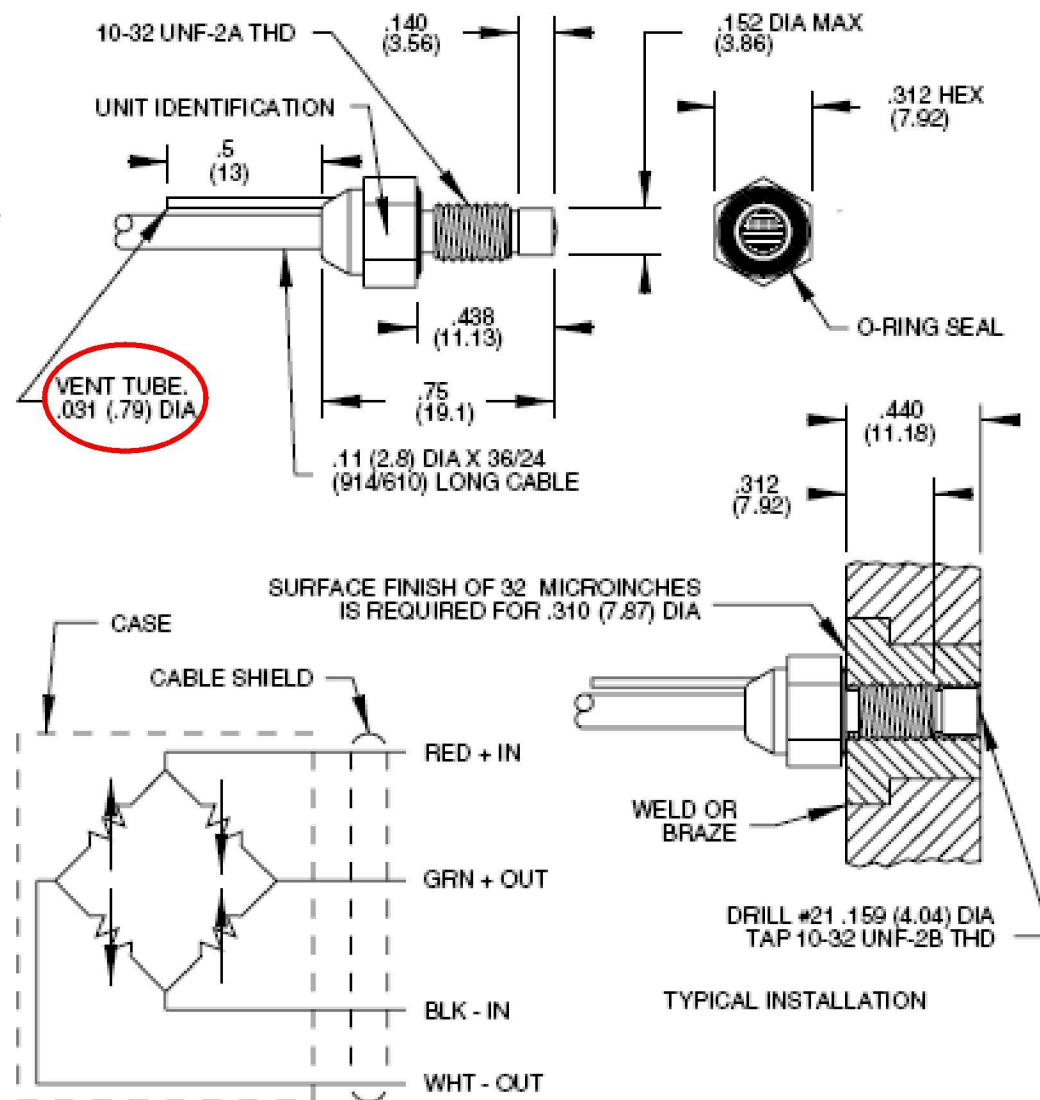
The Endevco 8510B-5 pressure transducer with a 6-inch vent tube extension shows significantly different low frequency response in the low frequency for side-by-side measurements with knotted versus unknotted vent tubes.



Dramatic differences in data are seen based on microphone vent tube installation. Further study was warranted.

Endevco 8510B-5

Piezoresistive Pressure Transducer



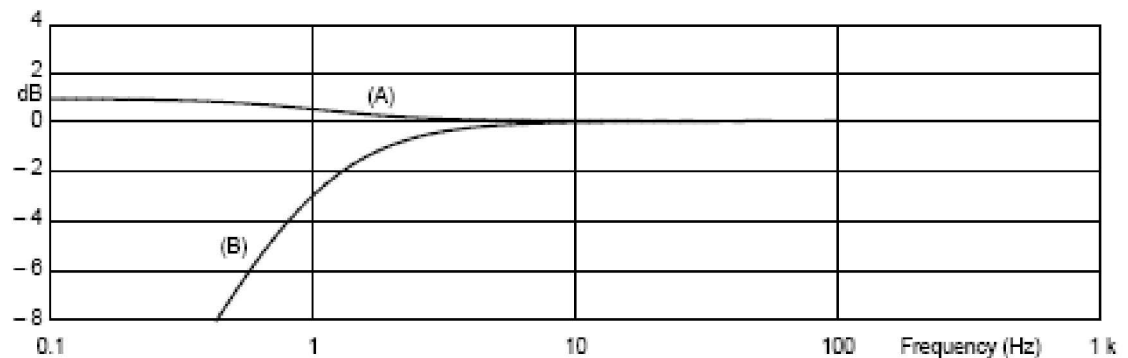
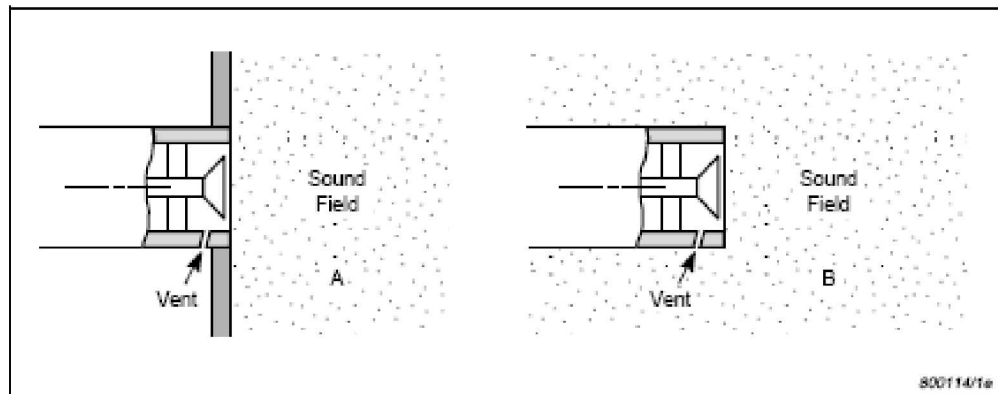
For many years, ATK used the Endevco 8510B-5 with a 6-inch “loosely knotted” shrink wrap vent tube (based on manufacturer recommendation).

For venting inside the acoustic field, the vent tube essentially acts as a first-order high-pass filter.

Better studied for condenser mics:

A: Venting outside field

B: Venting inside field



Source: B&K Microphone Handbook

High-pass filter cutoff frequency (-3 dB):

$$f = \frac{1}{2\pi RC}$$

R is the acoustic resistance
 C is the acoustic compliance

Acoustic resistance (R) :

$$R = \frac{8\mu L}{\pi a^4}$$

μ is the ordinary viscosity
 L is the tube length
 a is the tube radius

Acoustic compliance (C) :

$$C = \frac{V}{\gamma P_0}$$

V is the volume of the rear cavity
 γ is the ratio of specific heats
 P_0 is ambient pressure

Assumes: rigid-walled tube, stiff diaphragm, and that $L \gg a$

“A loosely-knotted 6-inch vent tube extension” was recommended by Endevco.

Addition of a vent tube extension will increase acoustical resistance R and lower the cutoff frequency.

Blocking of the vent tube:

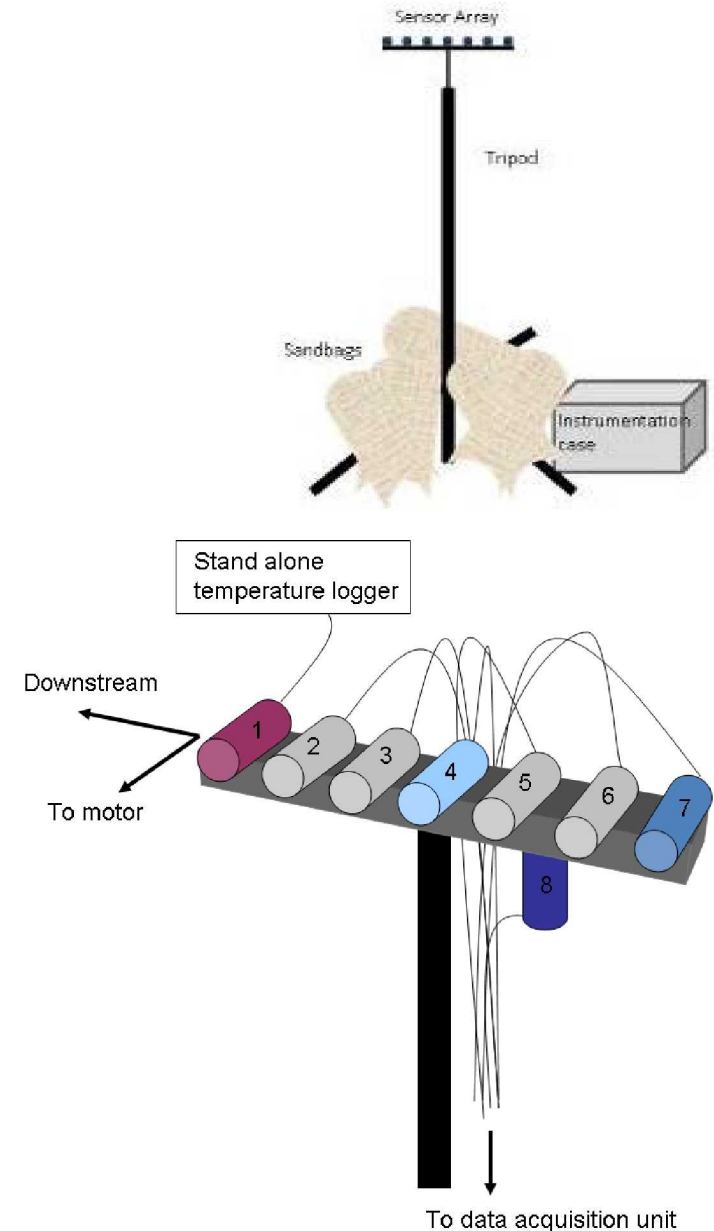
- The sensor back volume cannot equilibrate to changes in ambient pressure
- Will cause the sensor to measure any pressure changes
- May change the dynamic sensitivity of the sensor (equilibrium position of the sensor has changed)
- May damage the sensor or overload the amplifier if “static” pressure changes are too large (is likely why a “loosely-knotted” extension was prescribed)

A blocked vent tube can have undesirable effects on the resulting data and the acoustic sensor.

Instrumentation array at two locations (near motor and away from motor)

- 1. 12-bit HOBO® temperature smart sensor with HOBO Micro Station data logger**
- 2. Endevco 8510B-5 without vent tube extension*****
- 3. Endevco 8510B-5 with 6-inch heat shrink vent tube extension, open**
- 4. GRAS 40BH condenser microphone**
- 5. Endevco 8510B-5 with 6-inch heat shrink vent tube extension, knotted**
- 6. Endevco 8510B-5 with 60-inch Tygon (or similar) vent tube extension, open**
- 7. GRAS 40DD 1/8-inch IEPE microphone**
- 8. PCB 320C20 or equivalent accelerometer**

**** Field array vent tube extension broken off**



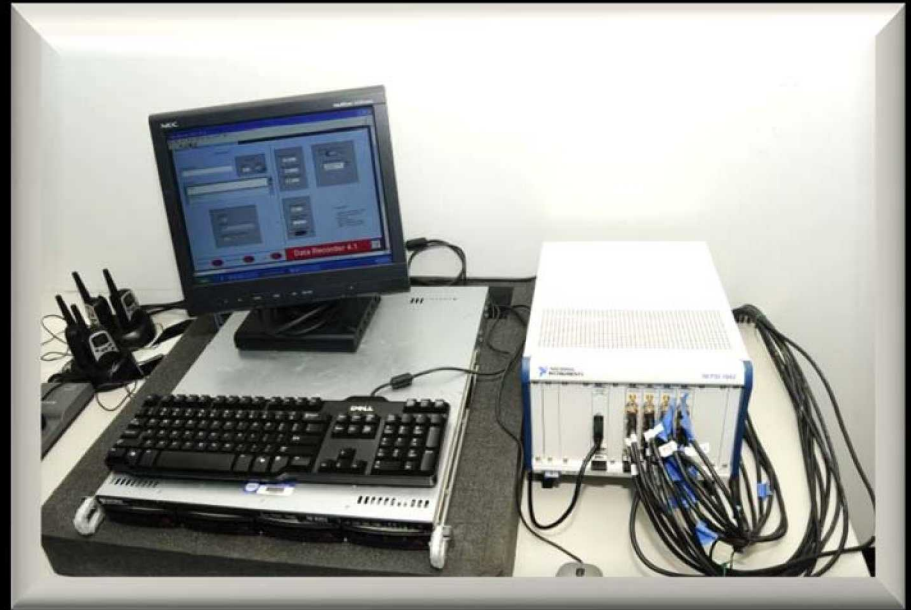
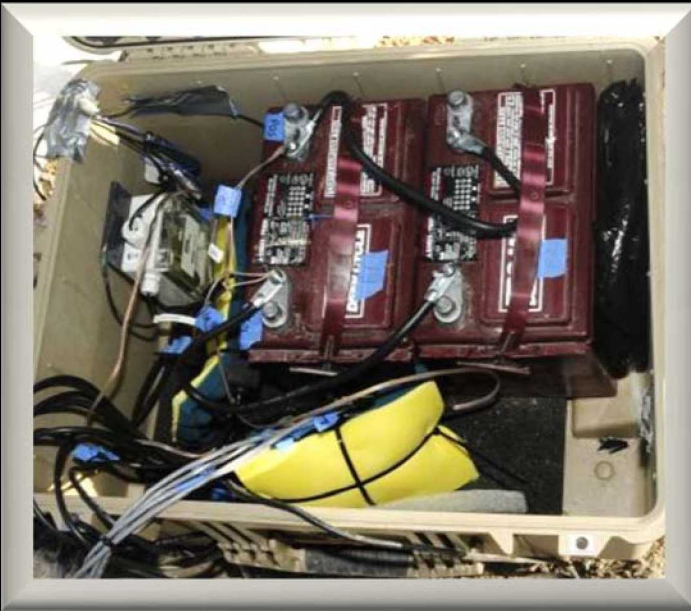
A premise

There were two arrays of instruments; one near the motor and one far from the motor on a hillside. No instruments were positioned on the motor for this test.

Near Motor
Measurements

Hillside
Measurements

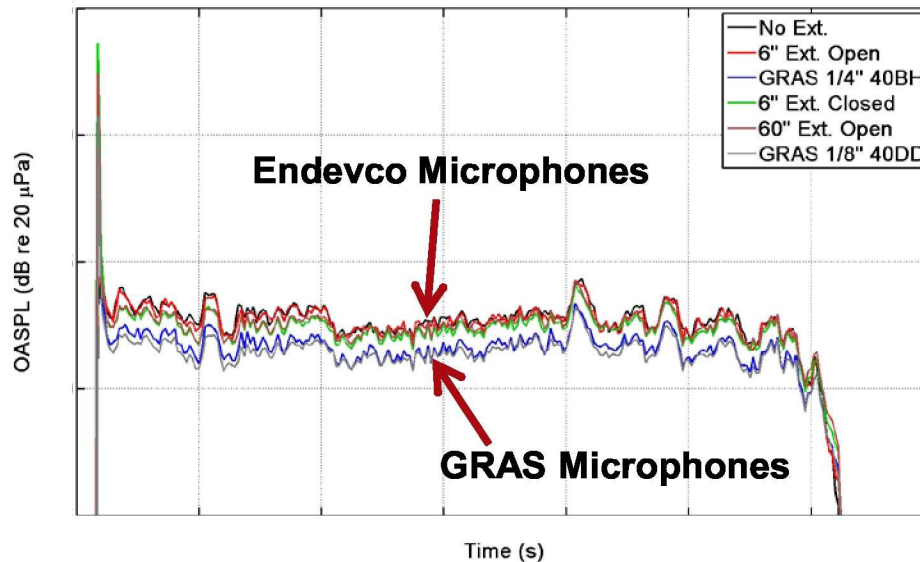




Data acquisition was carried out using National Instruments PXI-4462 24-bit cards and an NI-8353 server with 1 TB storage capability.

Sampling frequency rates were 204.8 kHz.

Acquisition was begun using a clock-based trigger at T-5 min. Acquisition stopped manually at ~T+30 min.

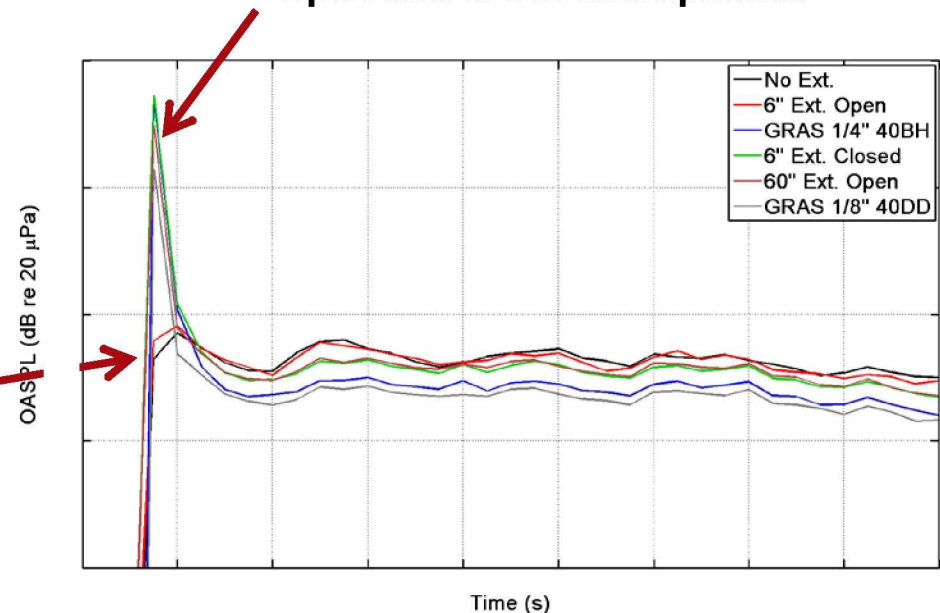


After the ignition overpressure, all sensors track each other to within ~1.5 dB.

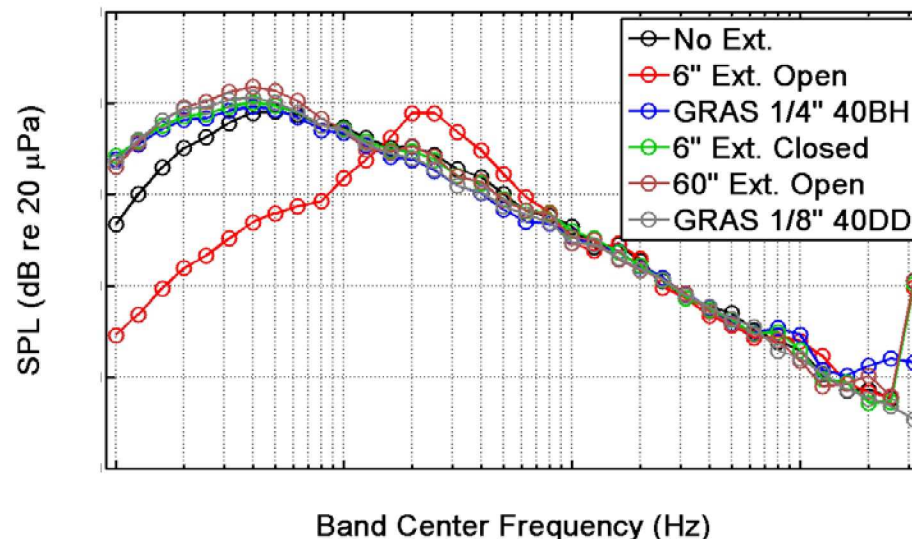
A similar result is seen at the field array.

Endevco 6-inch Closed, 60-inch Open and GRAS Microphones

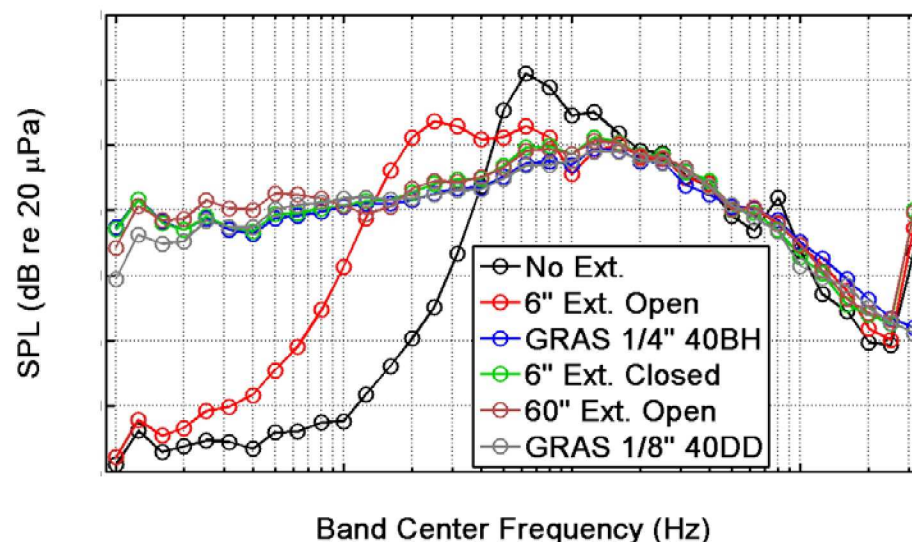
Endevco 6-inch Open and No Vent Tube Extension



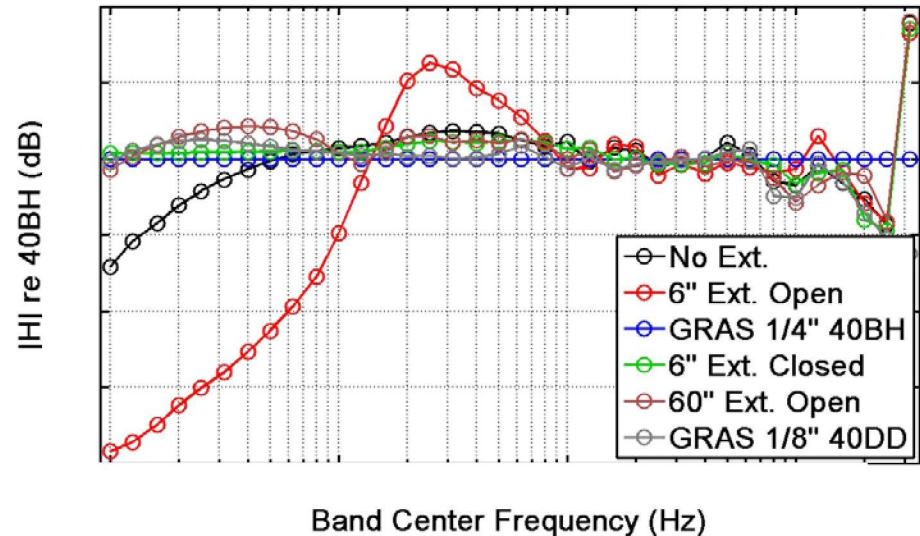
One-third octave spectra for **field** array averaged between T+90 and T+110 seconds.



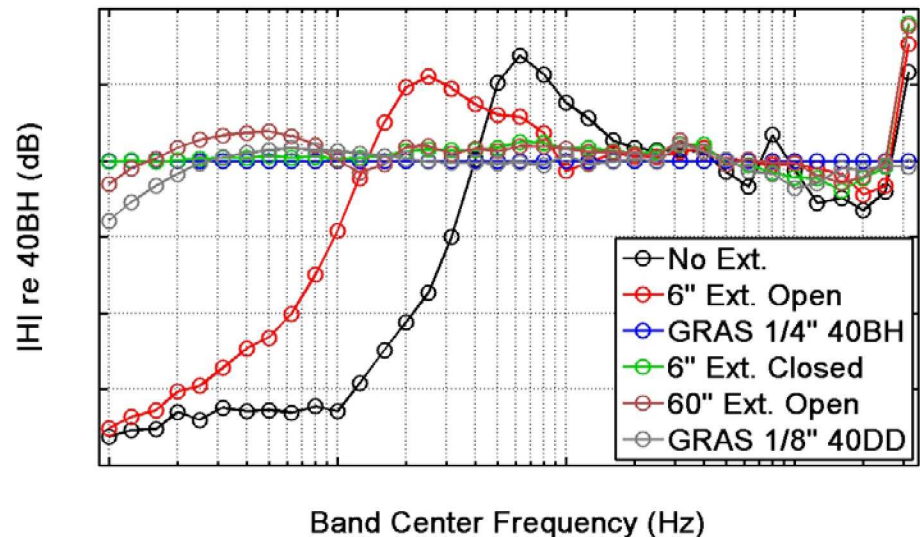
One-third octave spectra for **motor** array averaged between T+90 and T+110 seconds.



Transfer function magnitude for **field** array averaged between T+90 and T+110 seconds.



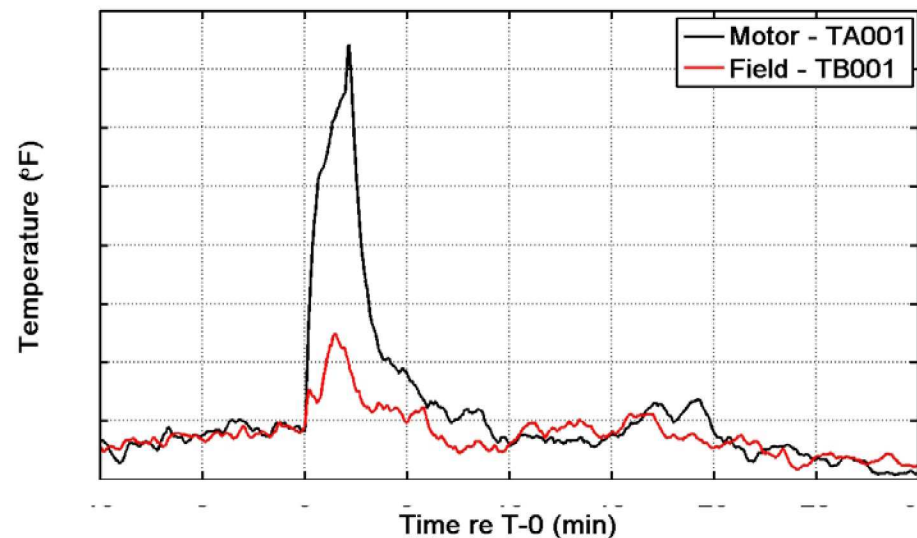
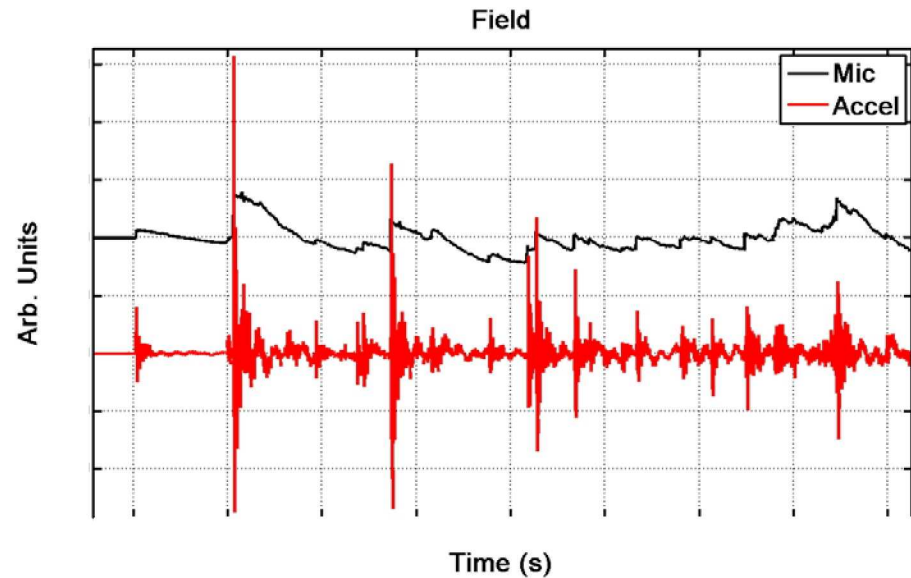
Transfer function magnitude for **motor** array averaged between T+90 and T+110 seconds.



- As the vent tube extension is lengthened, the amount of overshoot in amplitude is lessened and the frequency at which it approaches the 40BH microphone response is lowered. The lower cutoff frequency is in qualitative agreement with vent tube theory.
- The combination of overall level agreement and overshoot in amplitude response suggests a nonlinear, rather than linear, filter for the Endevco 8510B-5. (Overall level is preserved at both arrays, which see different noise fields.)
- Removal of the vent tube altogether actually lowers the cutoff frequency of the sensor, rather than raising it further. Vent tube theory no longer applies since the length is not much greater than the diameter.
- If the static pressure differences on opposite sides of the diaphragm can be assumed to negligibly affect the dynamic sensitivity and frequency response, the Endevco sensor with knotted vent tube extension appears to provide the best results. This is likely because the closed tube now appears infinitely long, which pushes the cutoff frequency of the sensor performance down to DC.

Vibrations are closely related to acoustic response on the tripods in the near and far field. **The acoustic loading on the structure is more severe when acoustic shocks are present, as is the case at the field array.**

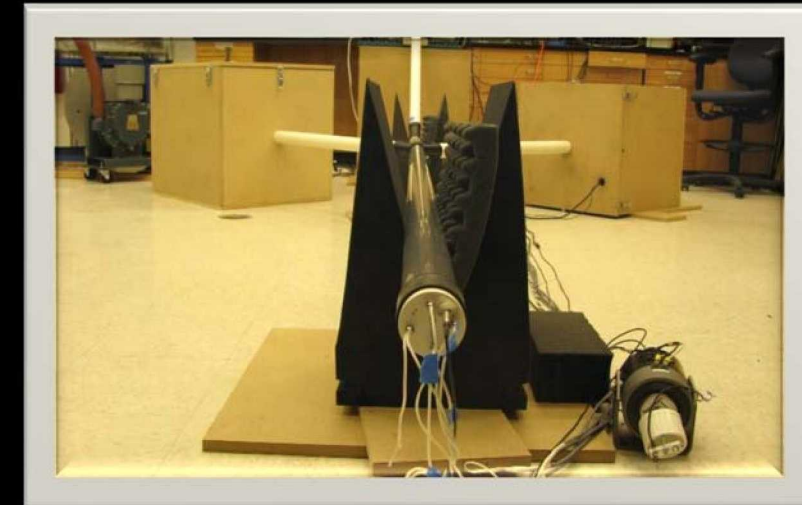
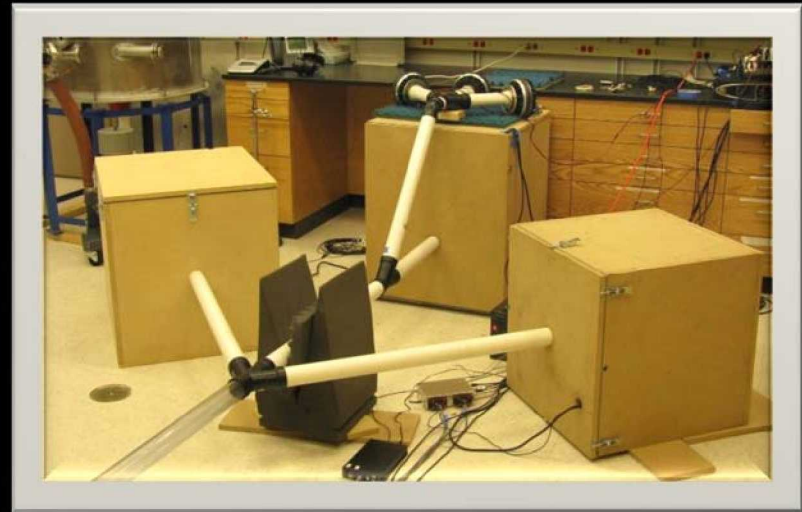
All microphones easily survived the rocket motor temperature environment.



Laboratory testing was performed at Brigham Young University Acoustics Lab.

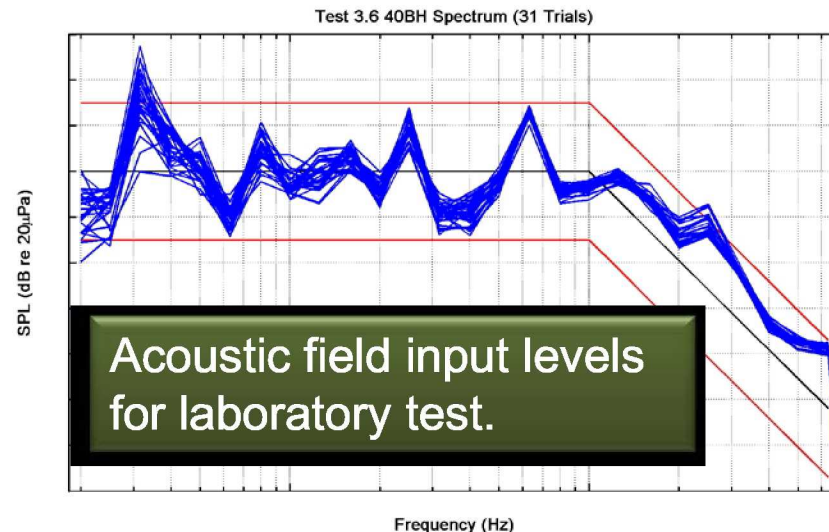
Test Objectives:

- Comparative response of multiple Endevco gages for the same vent tube configuration
- Changes in Endevco sensor and condenser microphone sensitivity to changes in acoustic amplitude
- Comparative response between the Endevco gages for different vent tube configurations and the condenser microphone
- Endevco and condenser microphone acoustic response to DM-1-based vibration input and sound field
- Changes in Endevco sensor and condenser microphone sensitivity to temperature effects
- Simulation of a rocket-like environment with high-amplitude acoustics, temperature, and vibration



The following vent tube configurations were tested:

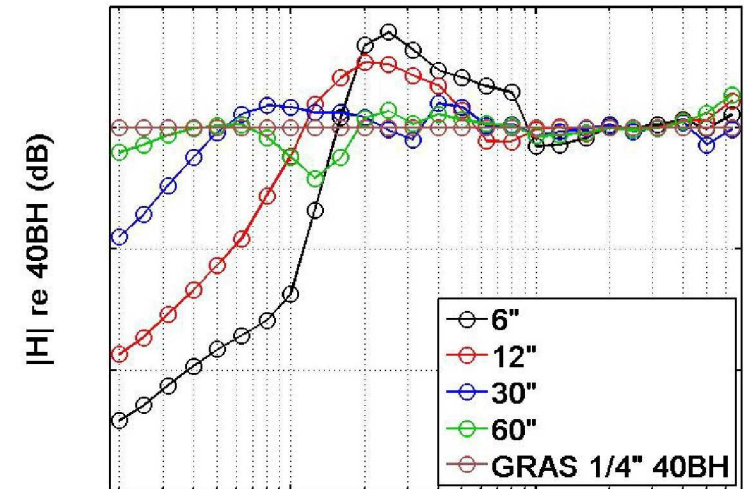
- 6, 12, 30, and 60-inch lengths of Tygon tubing were used as vent tube extensions. This was carried out with ambient and acoustic field venting.
- 6, 12, 30, and 60 inches of Tygon vent tube extensions with a knot placed near the end were used. This was carried out with ambient and acoustic field venting.
- 6 inches of shrink wrap vent tube extension (shrink wrap tubes were commonly in use until recently for this application). This was carried out with the extension both open and knotted and with ambient and acoustic field venting. In contrast to the other two parts of this test, this one was performed with shrink wrap on one Endevco while vent tubes were removed from the others.



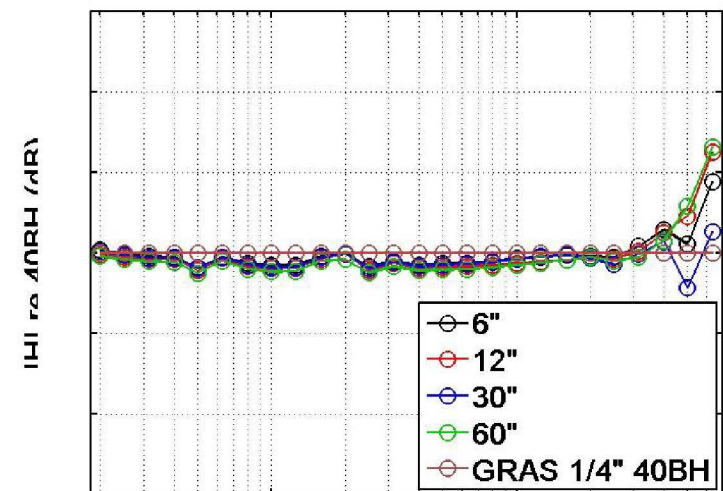
When the unknotted vent tube extensions were placed in the sound field, transfer functions were measured similar to the DM-1 test.

When the vent tubes were knotted or vented outside the sound field, the Endevco sensors and GRAS mic performed the same.

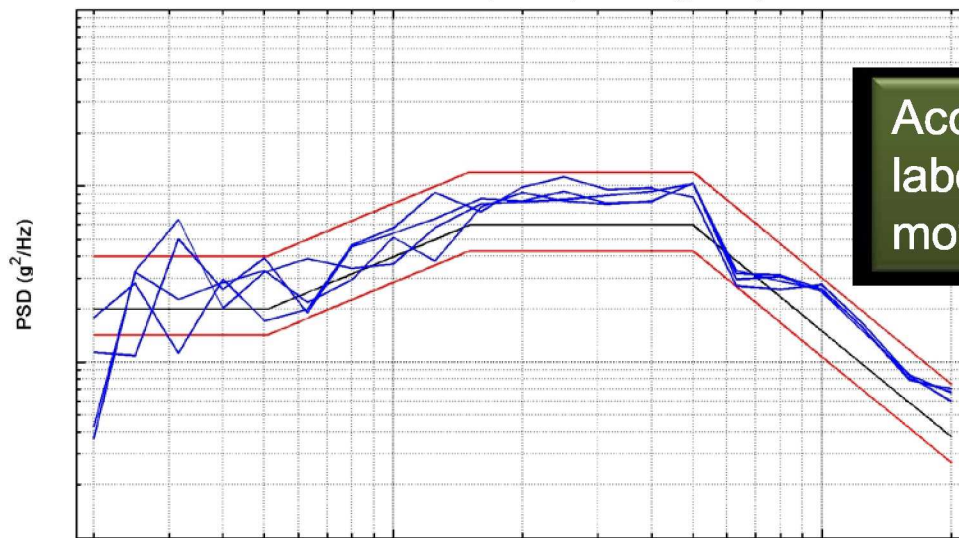
Test 3.6 Unknotted Field Vent Trial 1



Test 3.6 Knotted Field Vent Trial 1

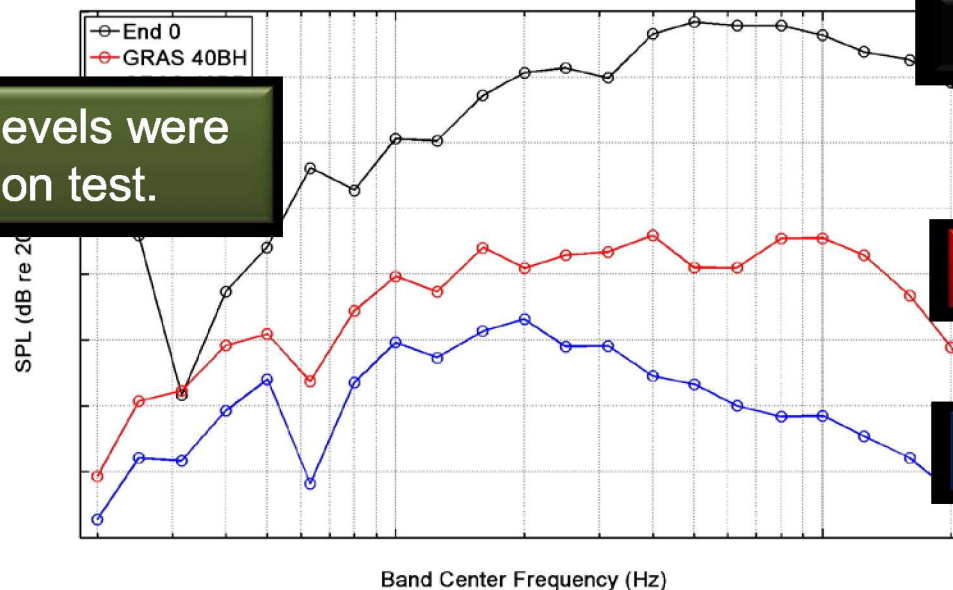


Test 3.7 Acceleration Spectrum (with Sound)(4 Trials)



Acceleration input levels for laboratory test were within rocket motor flight experience limits.

False sound pressure levels were produced by the vibration test.

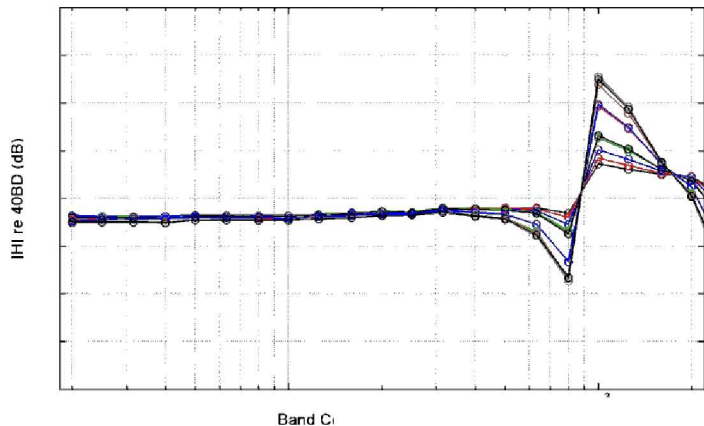


Endevco 8510B-5

GRAS 40BH

GRAS 40BD

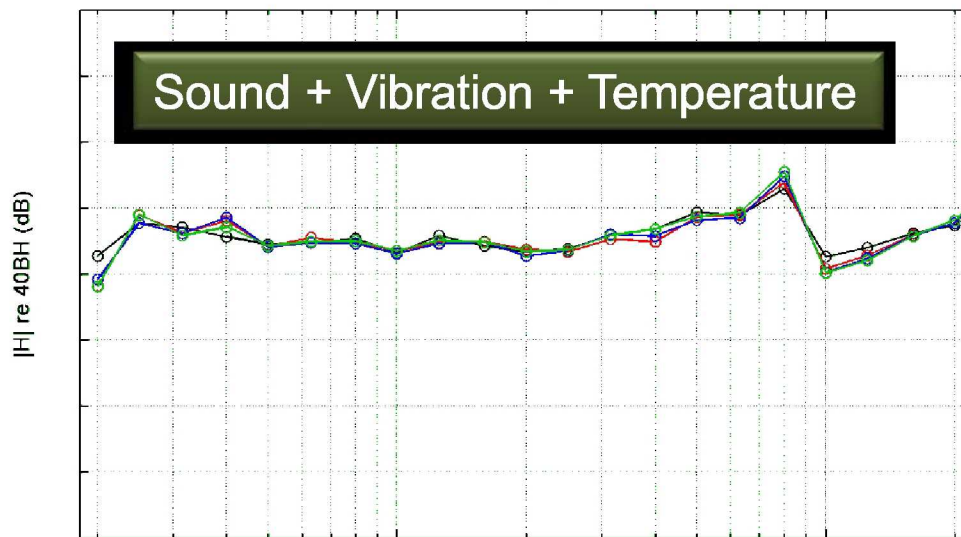
Test 3.8 (13 Trials) GRAS 40BH



Temperature from 79 to 132 F

Virtually no change in sensitivity was seen as a function of temperature for either sensor.

Test 3.9 (4 Trials) Endevco 0



Using a combination of all possible effects together (heat, vibration, sound), results were in comparable response when the knotted vent tube is used on the transducers.

8510B-5 may not have been meant to be used as a “microphone”

- The model 8510B is designed for a wide variety of aerospace, automotive, and industrial measurements which require a combination of small size, high sensitivity, and wideband frequency response. Its vent tube may be connected to a standard reference manifold or used for differential pressure measurements.

6-inch extension knotted provides the most similar response to the GRAS microphones

Appear to have measured the transfer functions for the different configurations (will verify in the lab)

Found rocket motor static test temperatures to be relatively mild, though hotter near motor and cooler in field than expected

Acceleration off motor is primarily due to acoustically-induced vibrations

Vent tube configuration has a dramatic effect on data in an open atmosphere acoustic environment.

- Using a 6-inch loosely knotted vent tube extension allows the Endevco 8510B-5 to operate as a microphone
- A 60-inch vent tube accurately represents an infinitely long extension, which operates as a microphone
- For rocket motor on-site live testing, alternative microphones are recommended
 - Results should not be dependent on installation practice

